BeamBeam3D: Code Improvements and Applications

Ji Qiang

Center of Beam Physics

Lawrence Berkeley National Laboratory

SciDAC II, COMPASS collaboration meeting, UCLA, Los Angeles, Dec 2, 2008

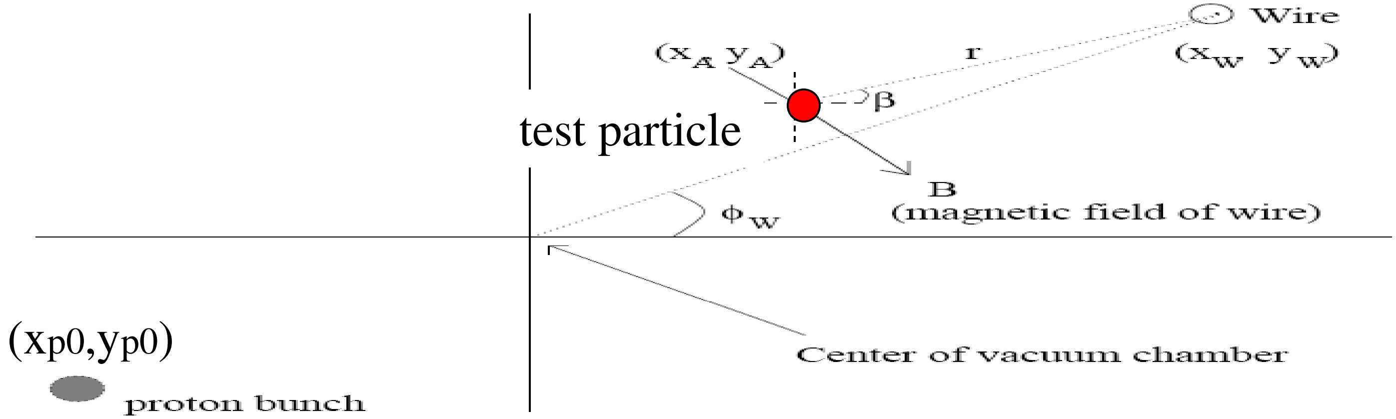
BeamBeam3D: Parallel Strong-Strong / Strong-Weak Simulation

- Multiple physics models:
  - strong-strong (S-S); weak-strong (W-S)
- Multiple-slice model for finite bunch length effects
- New algorithm -- shifted Green function -- efficiently models long-range parasitic collisions
- Parallel particle-based decomposition to achieve perfect load balance
- Lorentz boost to handle crossing angle collisions
- Arbitrary closed-orbit separation (static or time-dep)
- Independent beam parameters for the 2 beams
- Multiple bunches, multiple collision points
- Linear transfer matrix + one turn chromaticity

BeamBeam3D: Code Improvement

- Defects fixing
  - ✓ Single-precision in linear transfer map
  - ✓ Longitudinal synchrotron map
  - ✓ Luminosity output frequency
  - ✓ Multiple ID list
  - ✓ Time measurement for restart
- Thin lens sextupole model
- Quiet start for initial particle sampling
- Sampling particle trajectory diagnostic
- Beam transfer function diagnostic
- Conducting wire compensation model
- Distributed long-range soft-Gaussian beam-beam model
- Crab cavity compensation model
- Footprint diagnostic (in progress)

Model of Conducting Wire Compensation



$$\Delta x'_{BB} = \frac{2N_p r_p}{\gamma_p} \frac{x_A - x_{P0}}{[(x_A - x_{P0})^2 + (y_A - y_{P0})^2]} \left\{ 1 - \exp[-\frac{1}{2\sigma^2}[x_A - (x_{P0})^2 + (y_A - y_{P0})^2]] \right\}$$

$$\Delta y'_{BB} = \frac{2N_p r_p}{\gamma_p} \frac{y_A - y_{P0}}{[(x_A - x_{P0})^2 + (y_A - y_{P0})^2]} \left\{ 1 - \exp[-\frac{1}{2\sigma^2}[(x_A - x_{P0})^2 + (y_A - y_{P0})^2]] \right\}$$

$$\Delta x'_W = -\frac{B_y L}{(B\rho)} = \frac{\mu_0}{2\pi} \frac{I_W L}{(B\rho)} \frac{x_W - x_A}{(x_W - x_A)^2 + (y_W - y_A)^2}$$

$$\Delta y'_W = \frac{B_x L}{(B\rho)} = \frac{\mu_0}{2\pi} \frac{I_W L}{(B\rho)} \frac{y_W - y_A}{(x_W - x_A)^2 + (y_W - y_A)^2}$$

$$x_W = x_{P0}, \quad y_W = y_{P0},$$

$$\frac{\mu_0}{2\pi} \frac{I_W L}{(B\rho)} = \frac{2N_p r_p}{\gamma_p} \Rightarrow I_W L = ecN_p$$

B.Erdelyi and T.Sen, “Compensation of beam-beam effects in the Tevatron with wires,” (FNAL-TM-2268, 2004)

Thin Lens Approximation for Crab Cavity Deflection

$$x^{n+1} = x^{n}$$

$$Px^{n+1} = Px^{n} + \frac{qV}{E_s}\sin(\omega z^{n}/c)$$

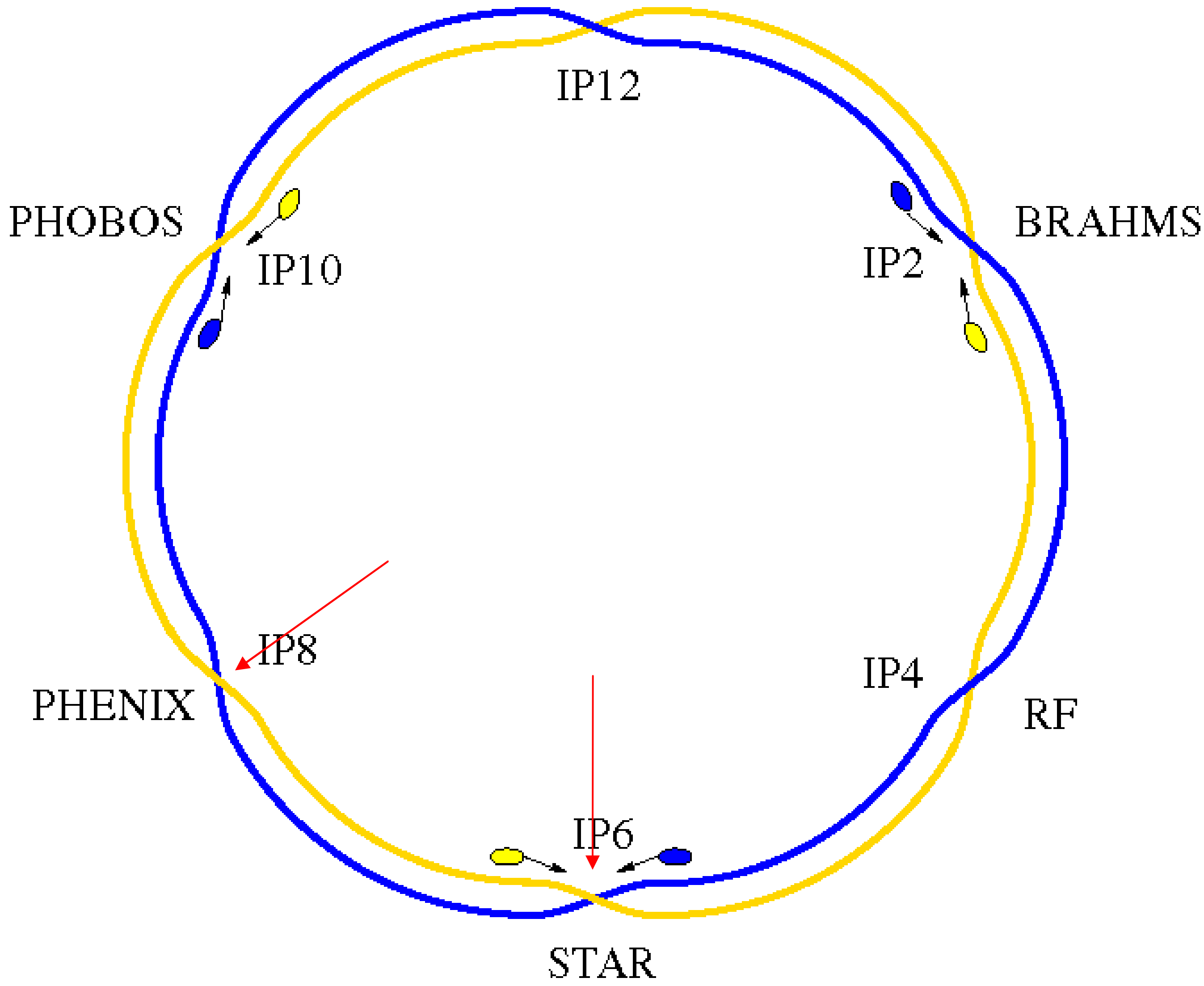
$$z^{n+1} = z^{n}$$

$$\delta E^{n+1} = \delta E^{n} + \frac{qV}{E_s}\cos(\omega z^{n}/c)x^{n}$$

$$here \;:$$

$$V = \frac{cE_s \tan\phi}{\omega\sqrt{\beta_{x,crab}\beta_x^{*}}}$$

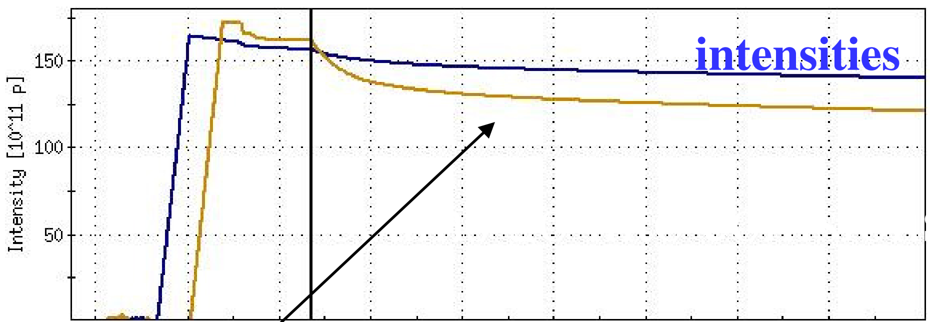
BeamBeam3D Applications to RHIC

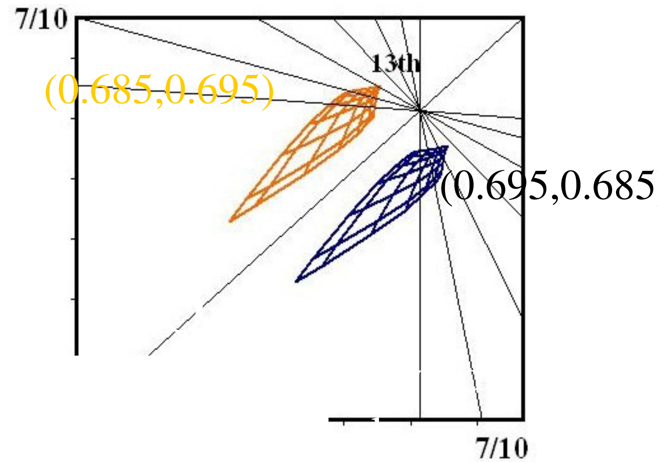


RHIC Physical Parameters for the Tune Scan Simulations

Beam energy (GeV)	100
Protons per bunch	20e10
β* (m)	0.8
Rms spot size (mm)	0.14
Betatron tunes (blue)	(0.695,0.685)
Rms bunch length (m)	0.8
Synchrotron tune	5.5e-4
Momentum spread	0.7e-3
Beam-Beam Parameter	0.00977
Chromaticity	(2.0, 2.0)

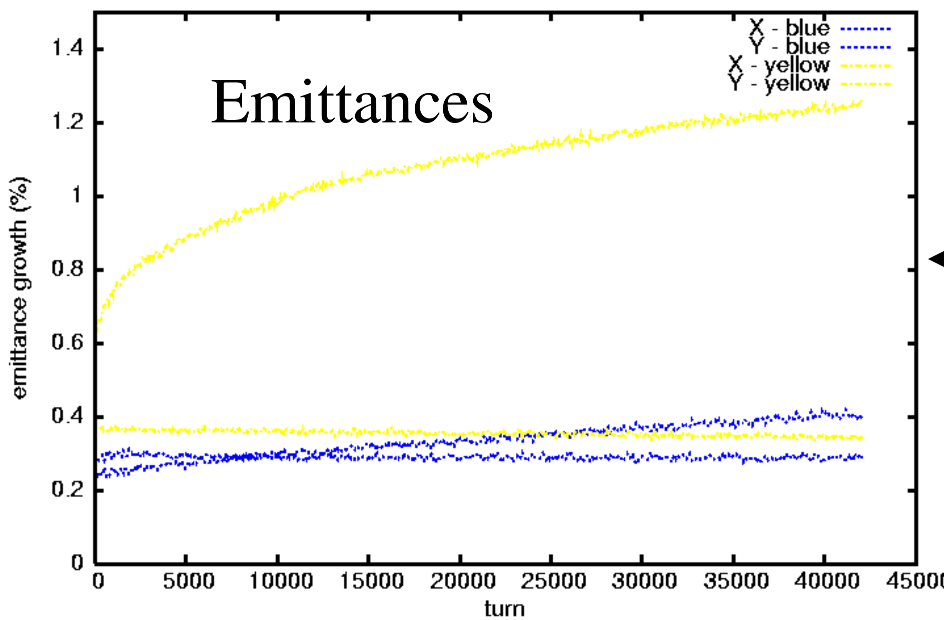
Intensity (experiment) and Emittance (simulation) Evolution of Blue and Yellow Proton Beams at RHIC





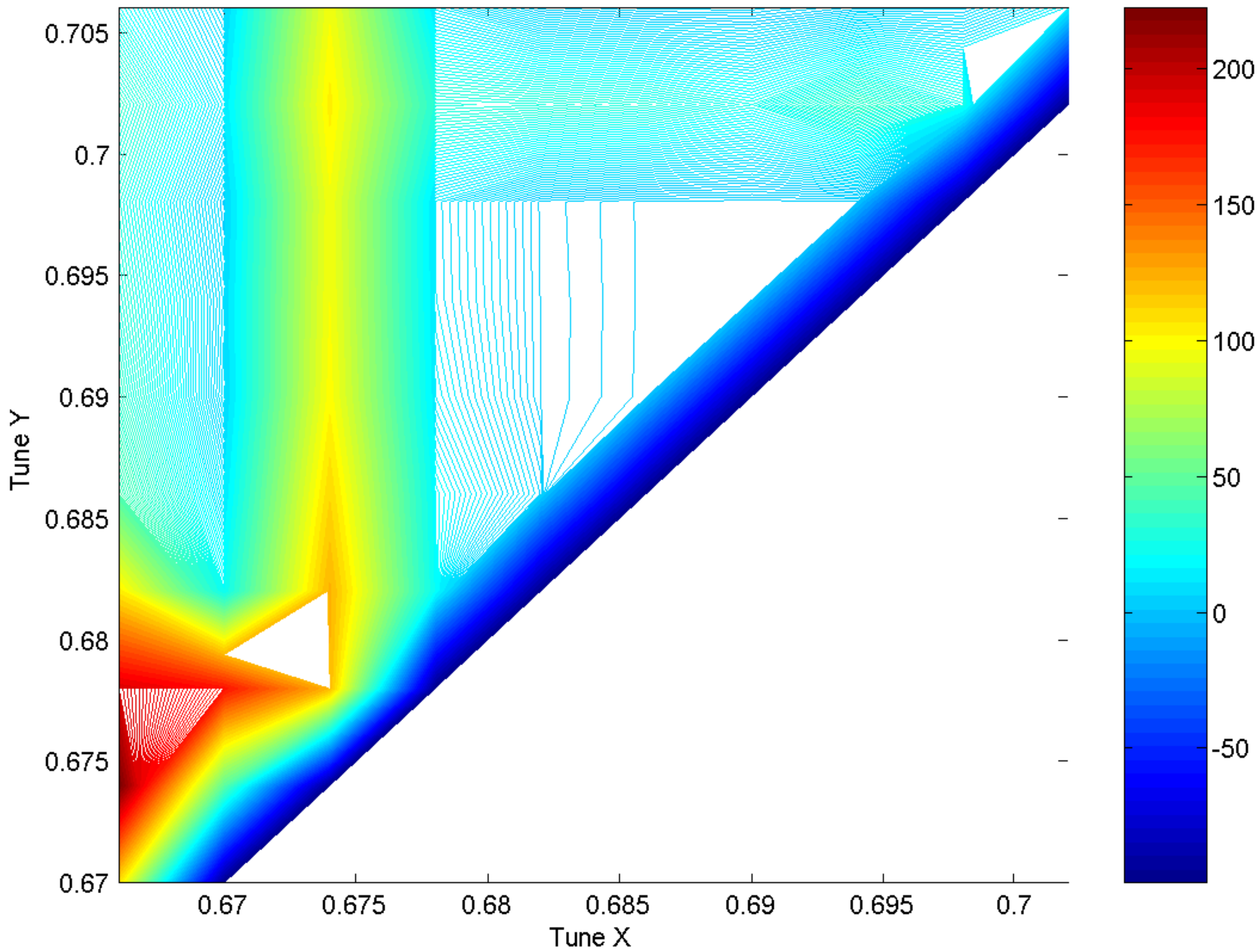
measurements

(from W. Fischer, et al.)

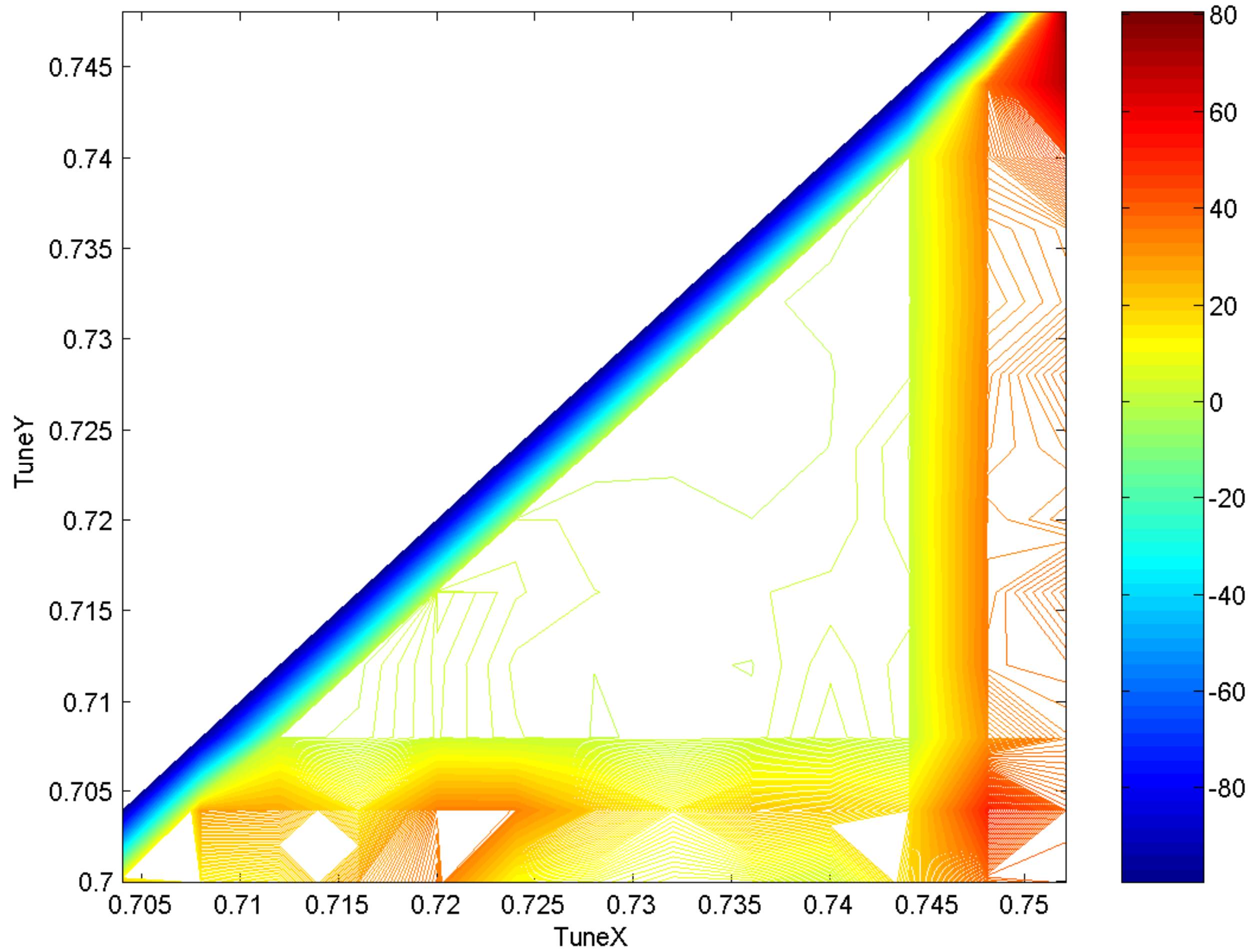


simulation

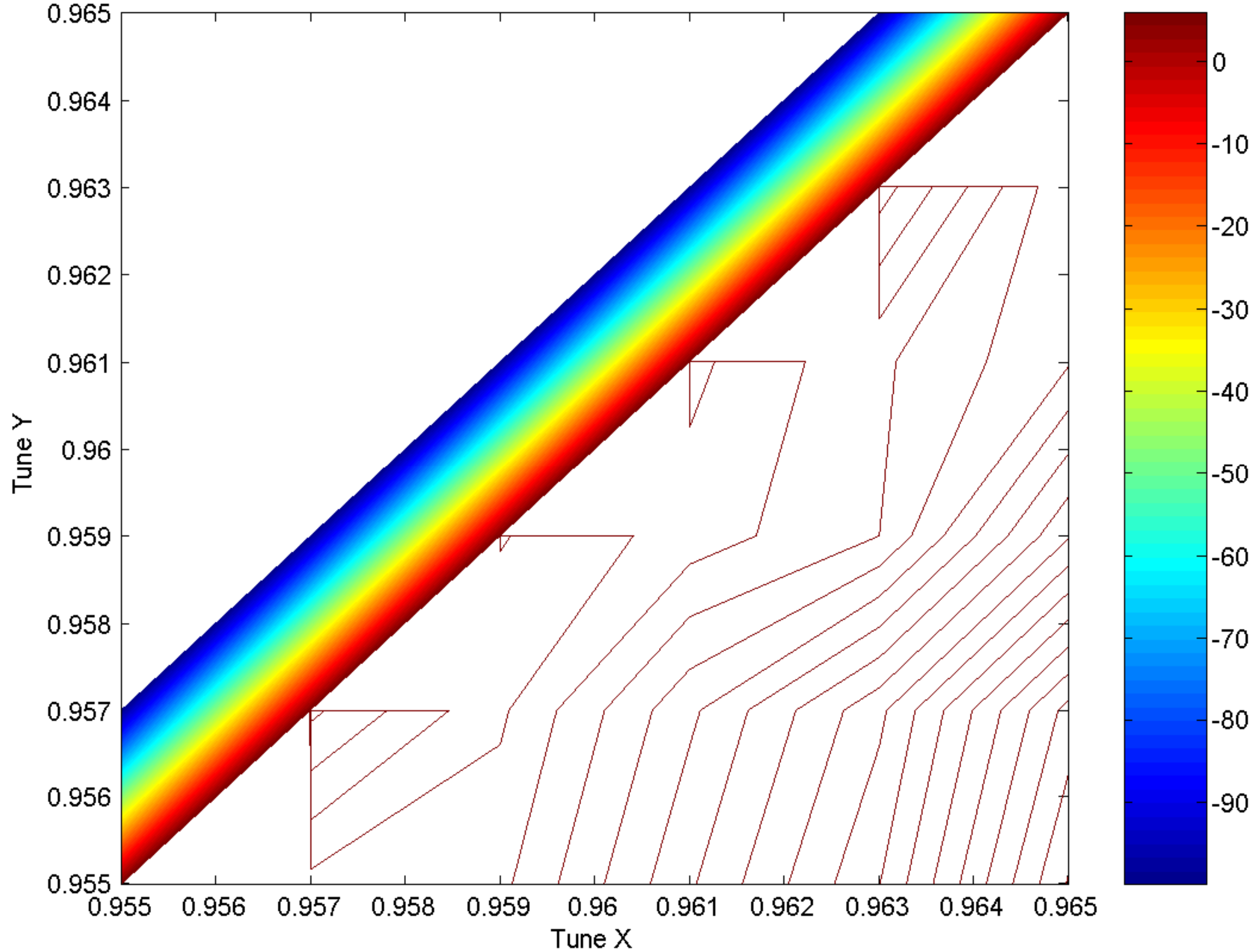
Averaged Emittance Growth vs. Tunes (near half integer, above diagonal)



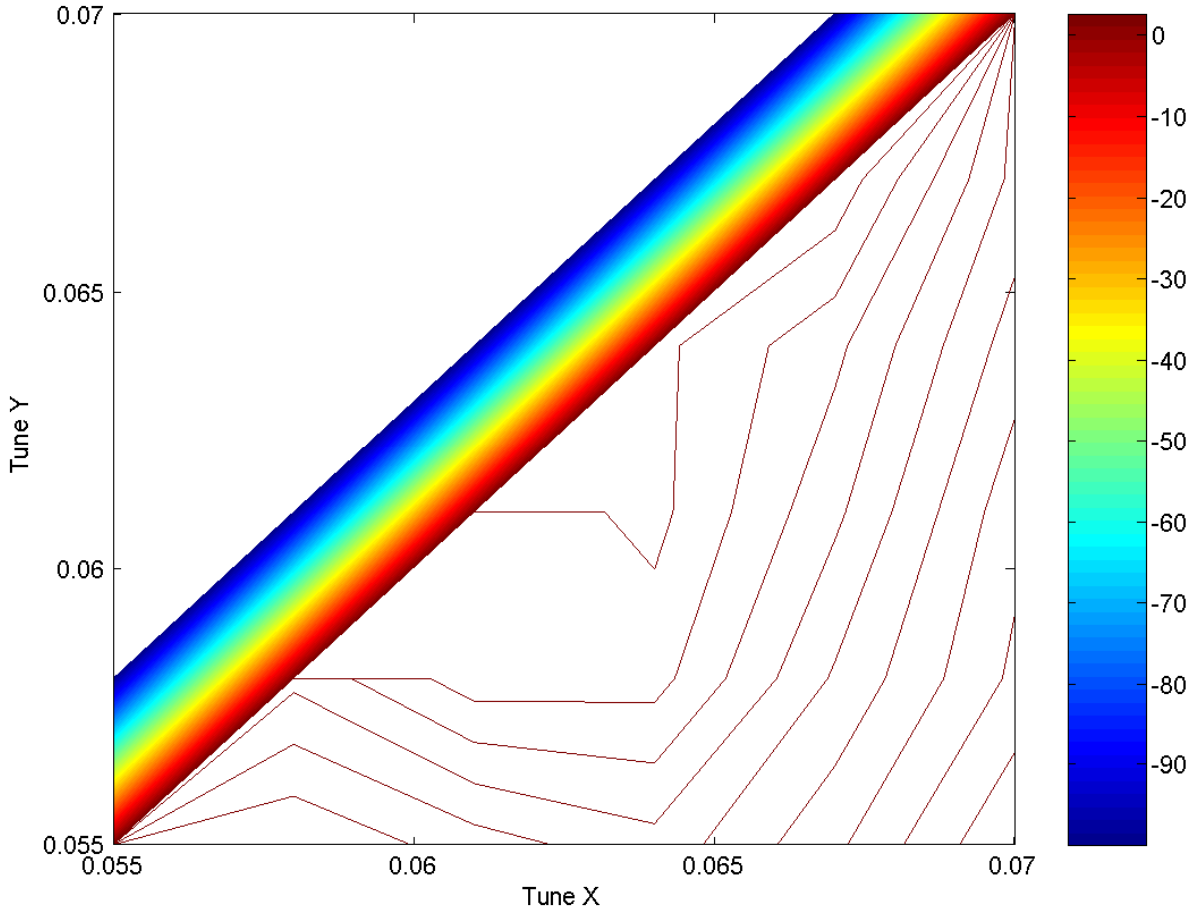
Averaged Emittance Growth vs. Tunes (near half integer, below diagonal)



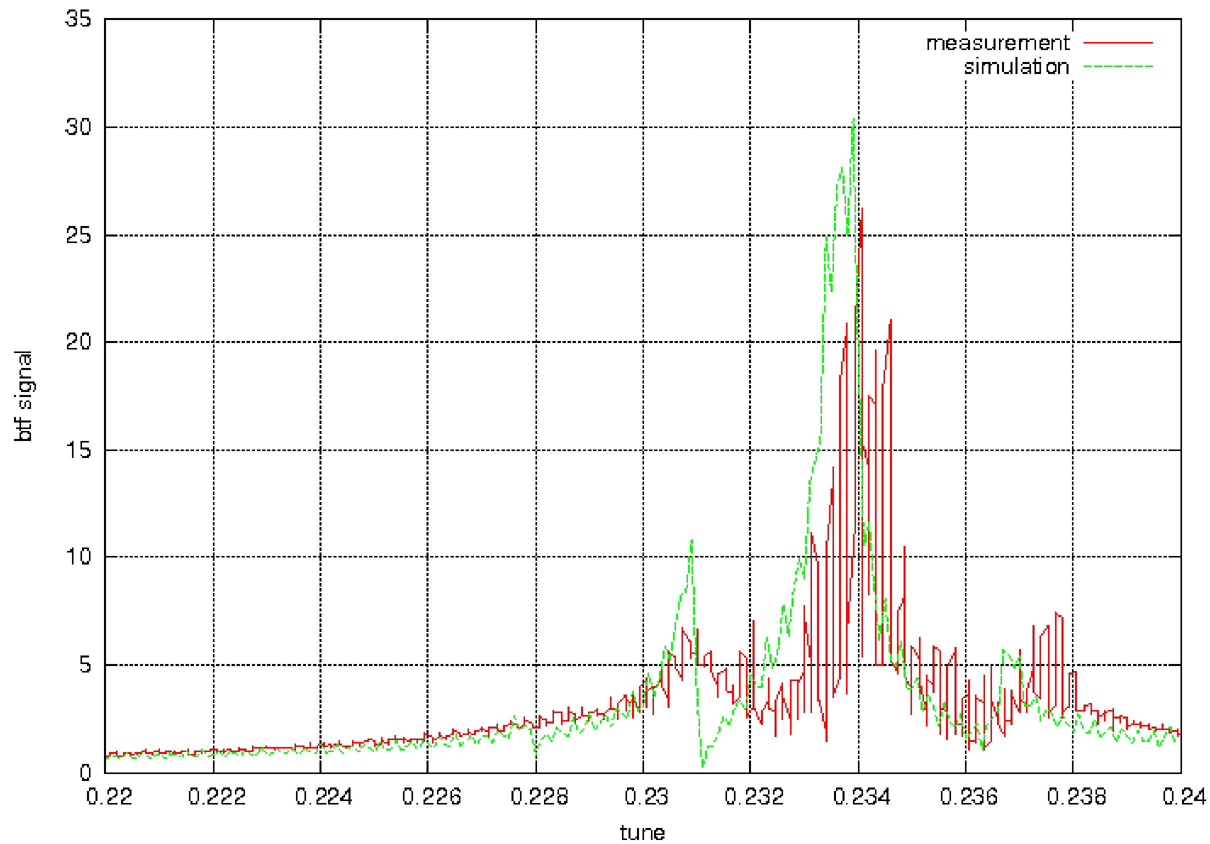
Averaged Emittance Growth vs. Tunes (below integer, below diagonal)



Averaged Emittance Growth vs. Tunes (above integer, below diagonal)

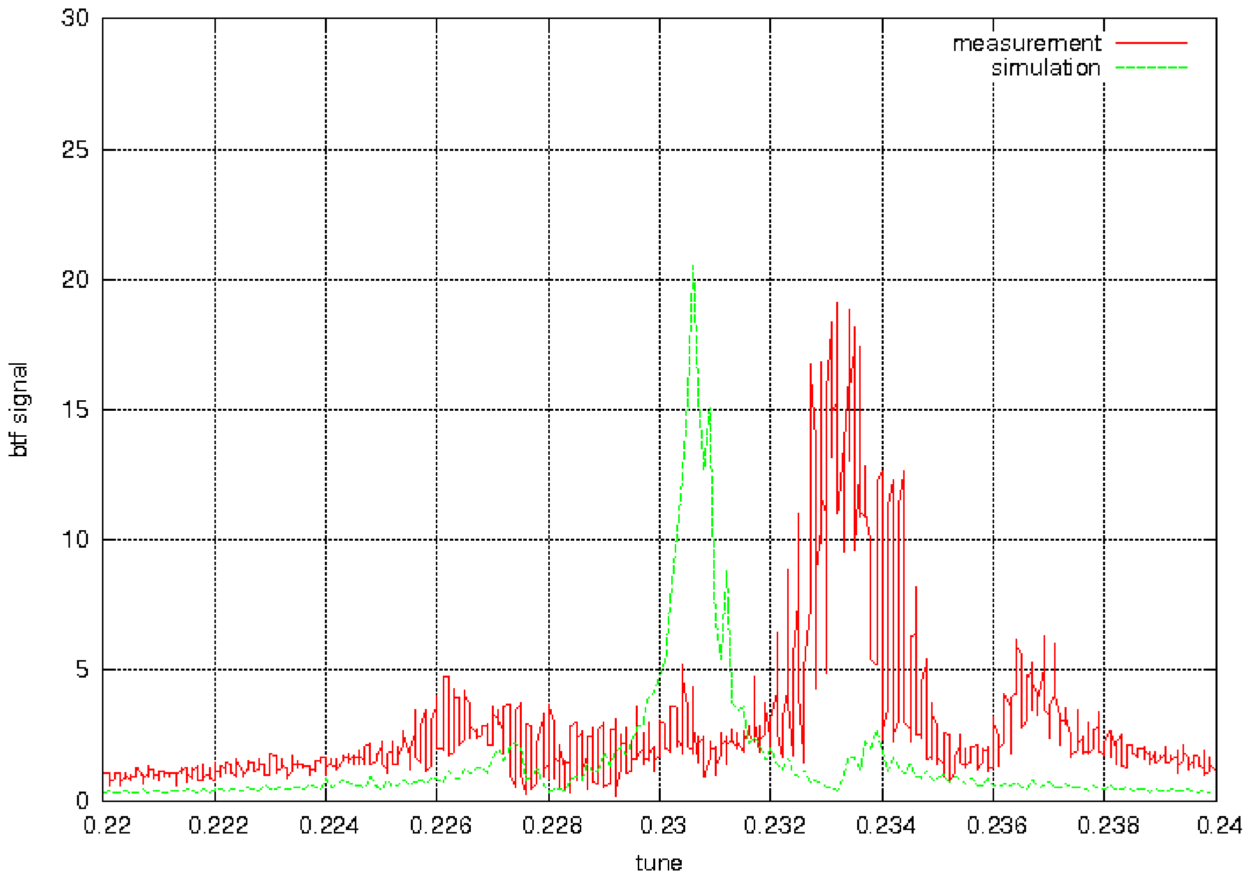


Simulated and Measured BTF Signal at RHIC without Compensation Wire

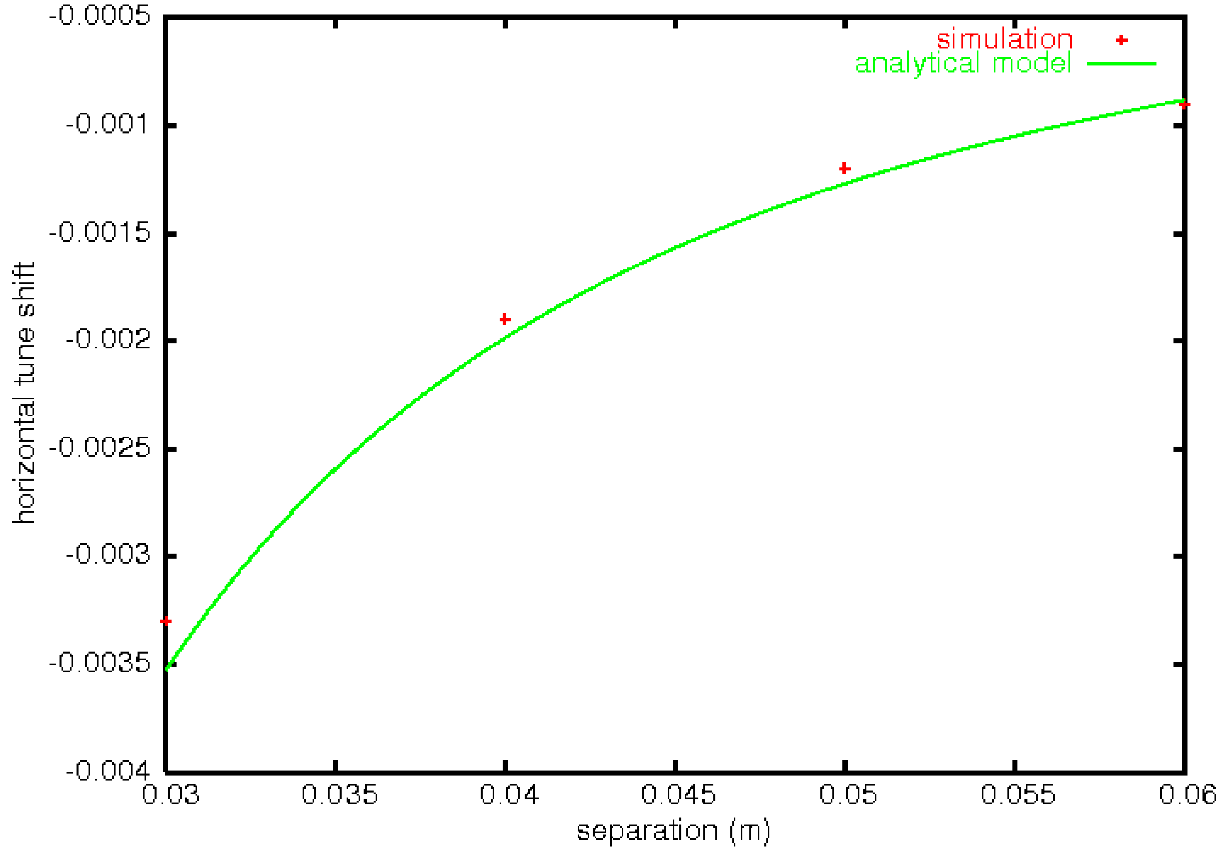


http://www.agsrhichome.bnl.gov/AP/BeamBeam/BTF/

Simulated and Measured BTF Signal at RHIC with 50 A Compensation Wire and 30 mm Separation



Tune Shift vs. Separation from Simulated BTF Signal and Analytical Model with 50 A Compensation Wire

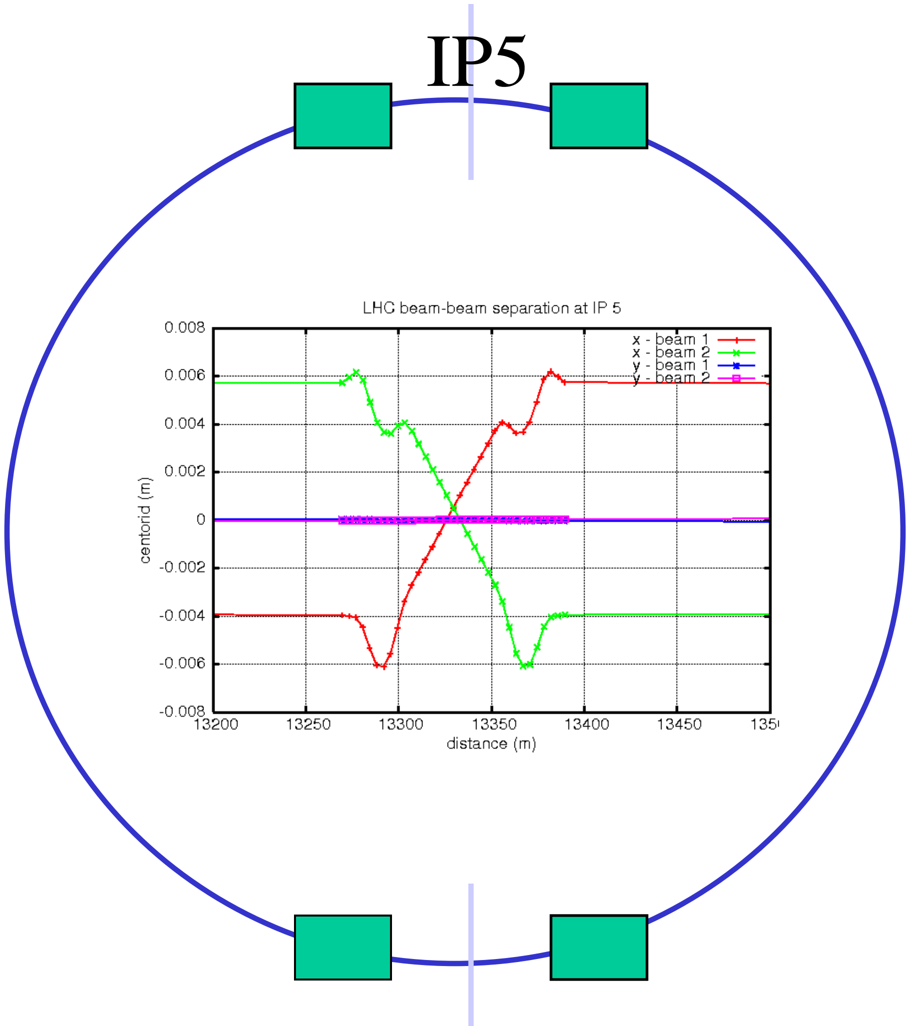


$$\Delta\nu_x(W) = -\frac{\mu_0}{8\pi^2(B\rho)}\beta_x\left[\frac{I_W L\ \cos 2\theta_W}{r_W^2}\right], \quad \Delta\nu_y(W) = +\frac{\mu_0}{8\pi^2(B\rho)}\beta_y\left[\frac{I_W L\ \cos 2\theta_W}{r_W^2}\right]$$

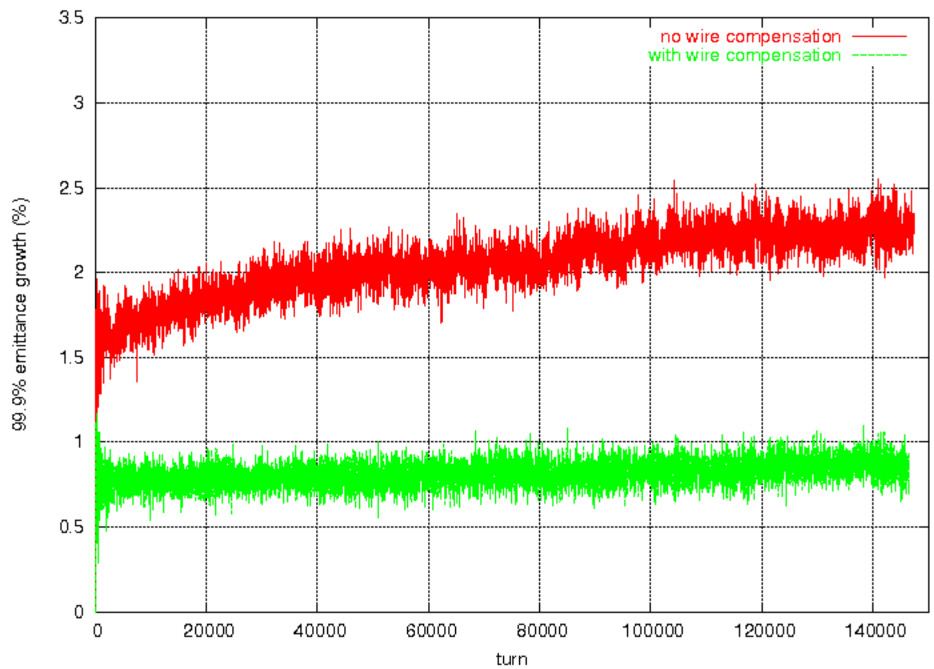
B.Erdelyi and T.Sen, "Compensation of beam-beam effects in the Tevatron with wires," (FNAL-TM-2268, 2004).

Strong-Strong Beam-Beam Simulation LHC Wire Compensation (2 Head-On + 64 Long Range)

IP5

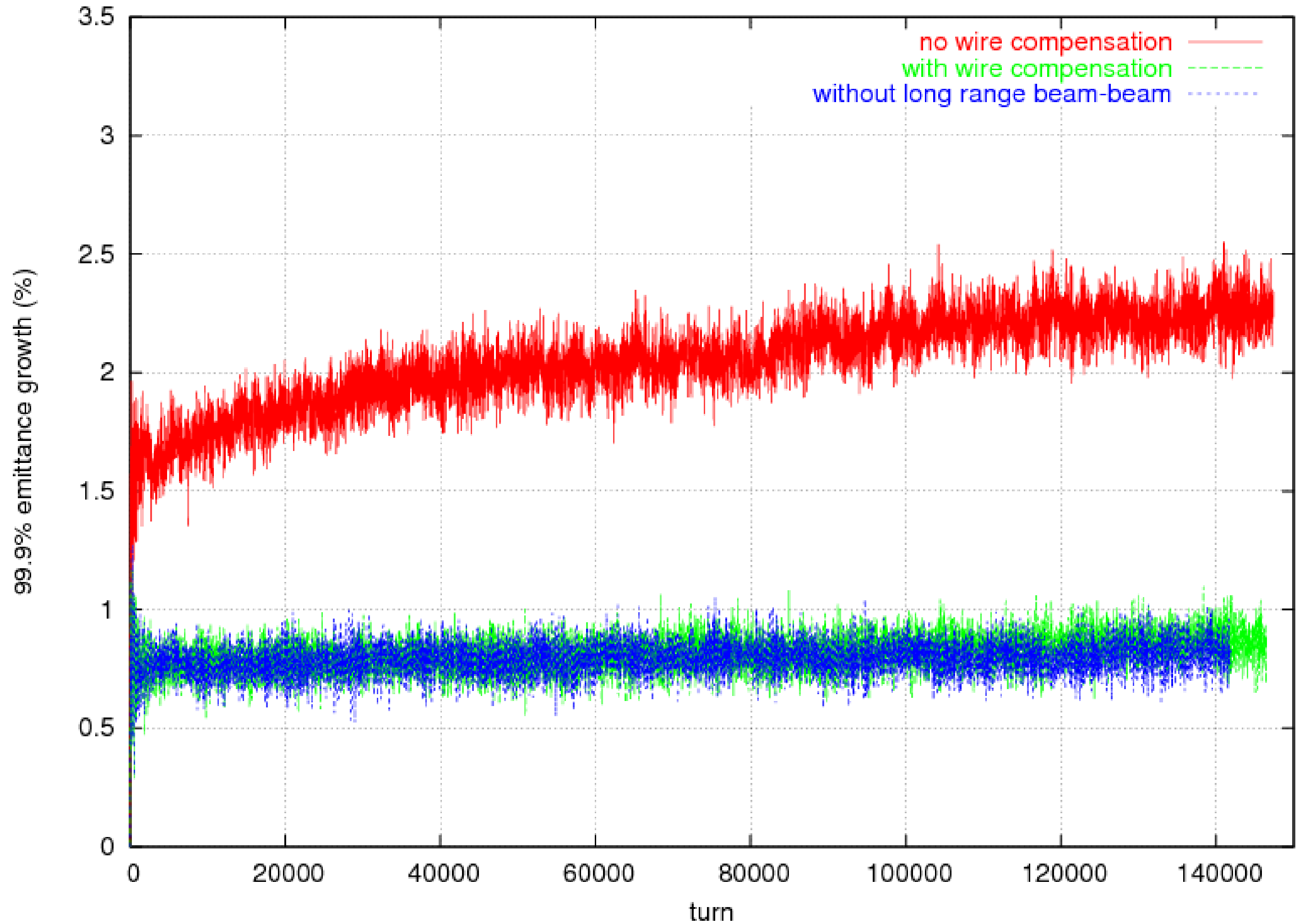


IP1

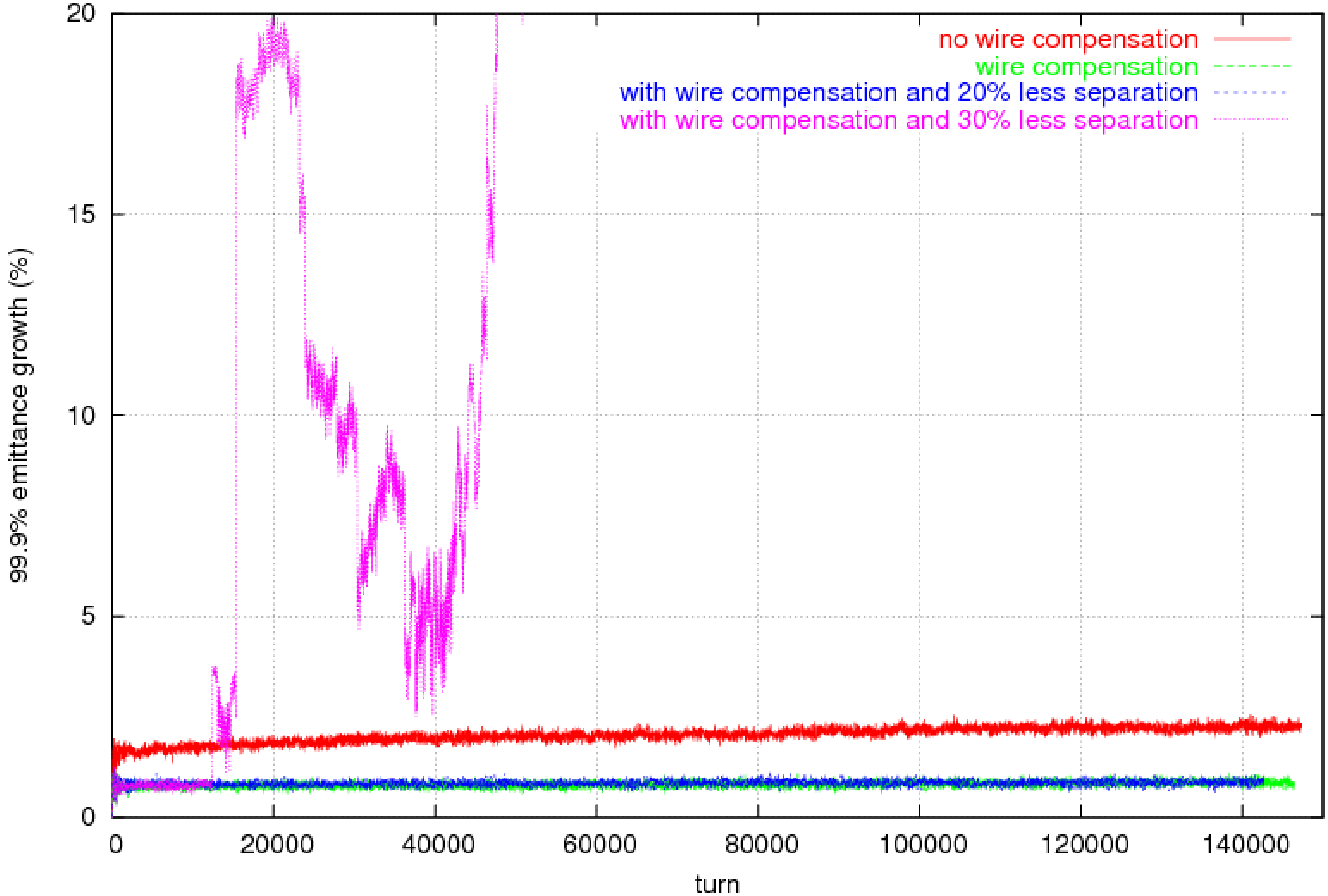


J. Qiang, LBNL

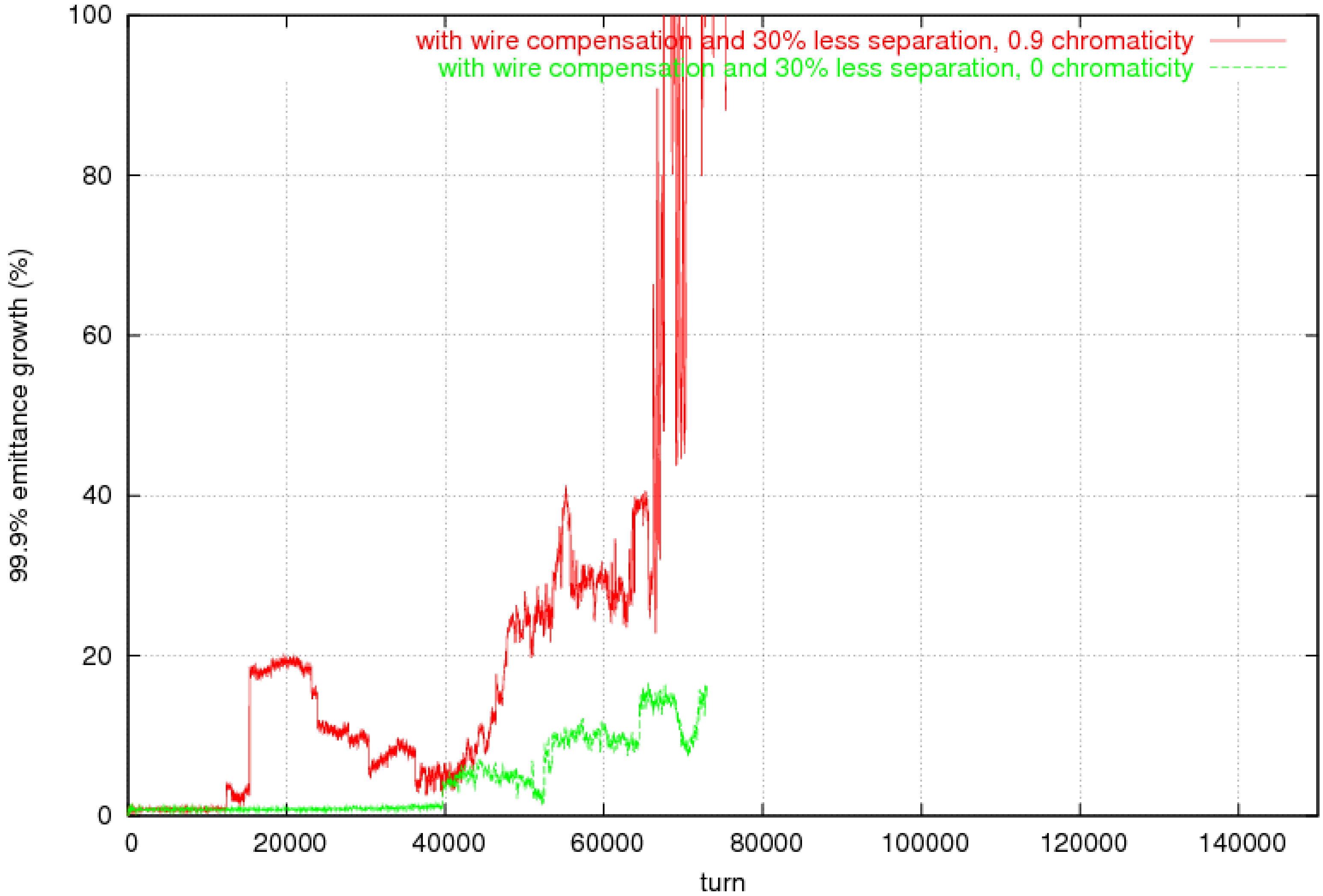
Emittance Growth Evolution w/o Wire Compensation



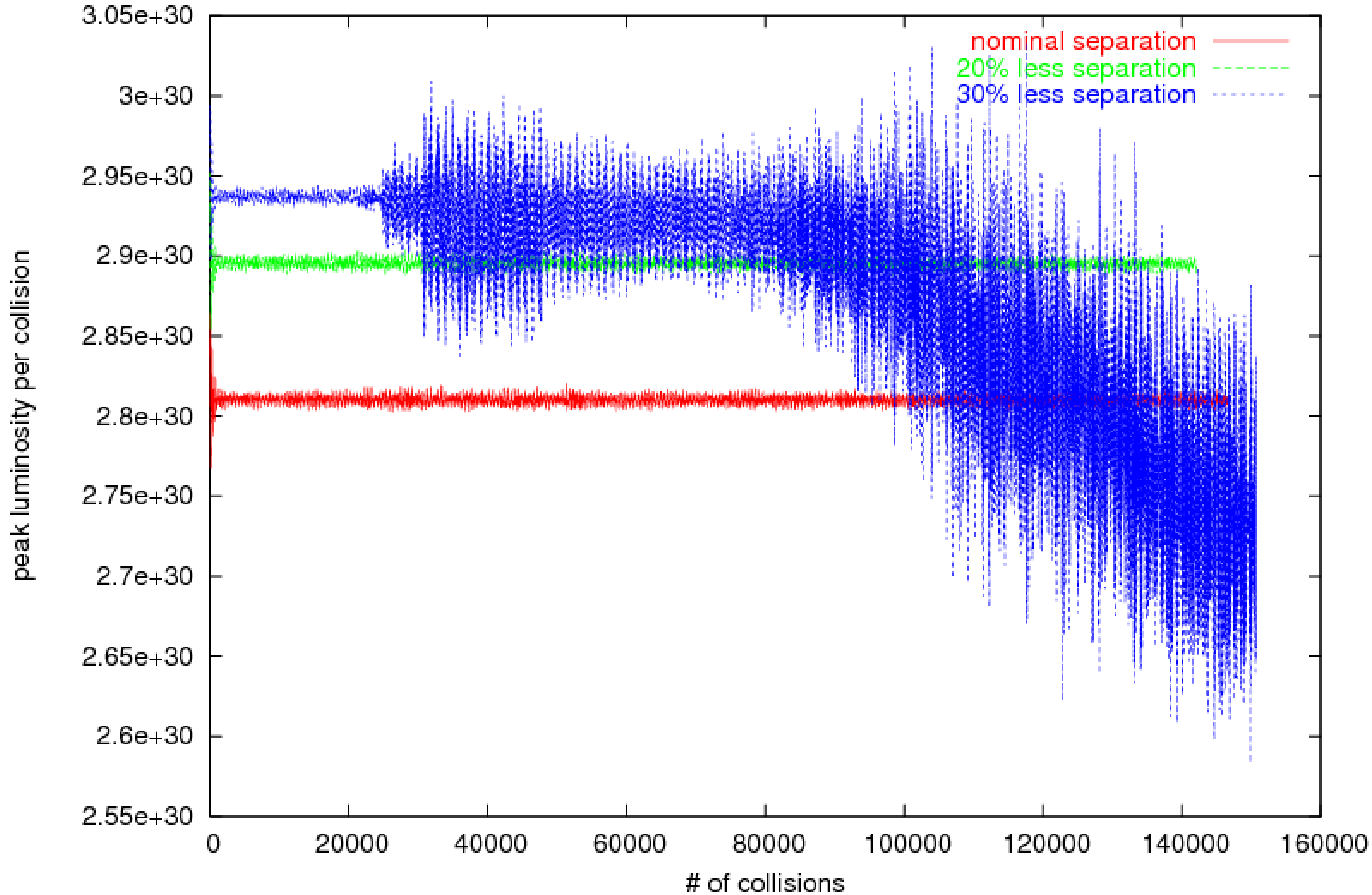
Emittance Growth Evolution with Reduced Separation



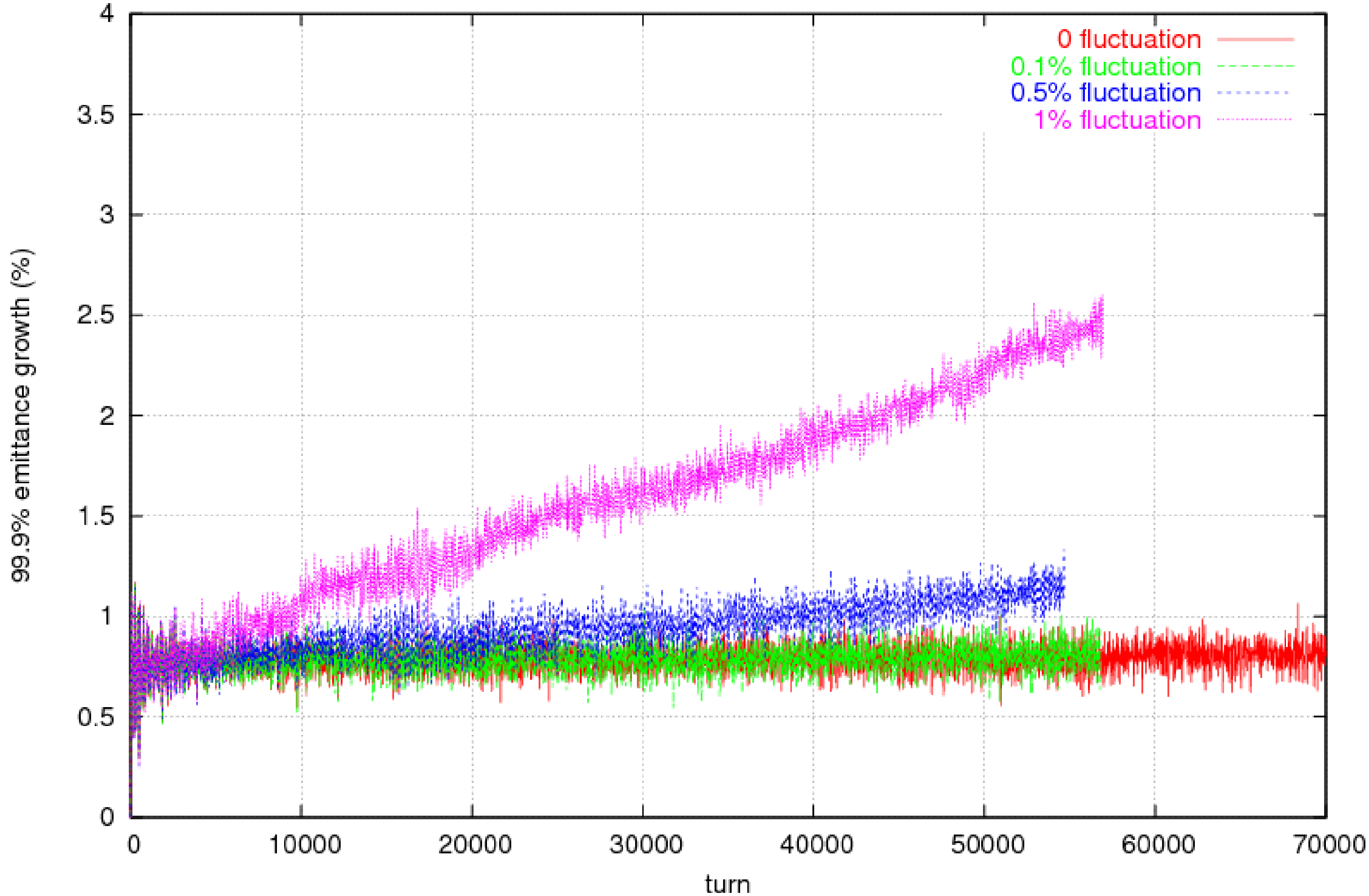
Emittance Growth Evolution w/o Machine Chromaticity



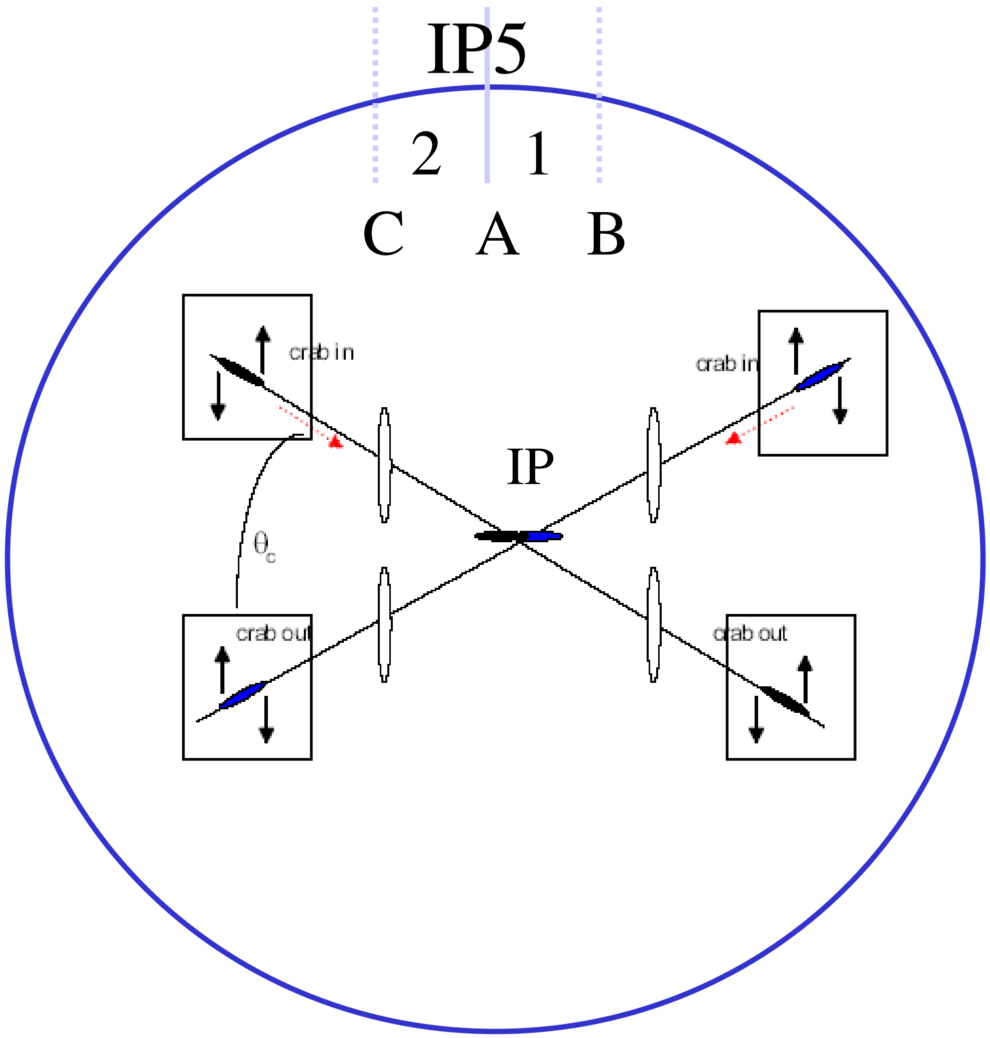
Luminosity Evolution with Reduced Separation



Emittance Growth Evolution with Current Fluctuation



A Schematic Plot of LHC Collision at 1 IP and Crab Cavities



One Turn Transfer Map with Beam-Beam and Crab Cavity

$$M = Ma\ M1\ Mb\ M1^{-1}\ M\ M2^{-1}\ Mc\ M2$$

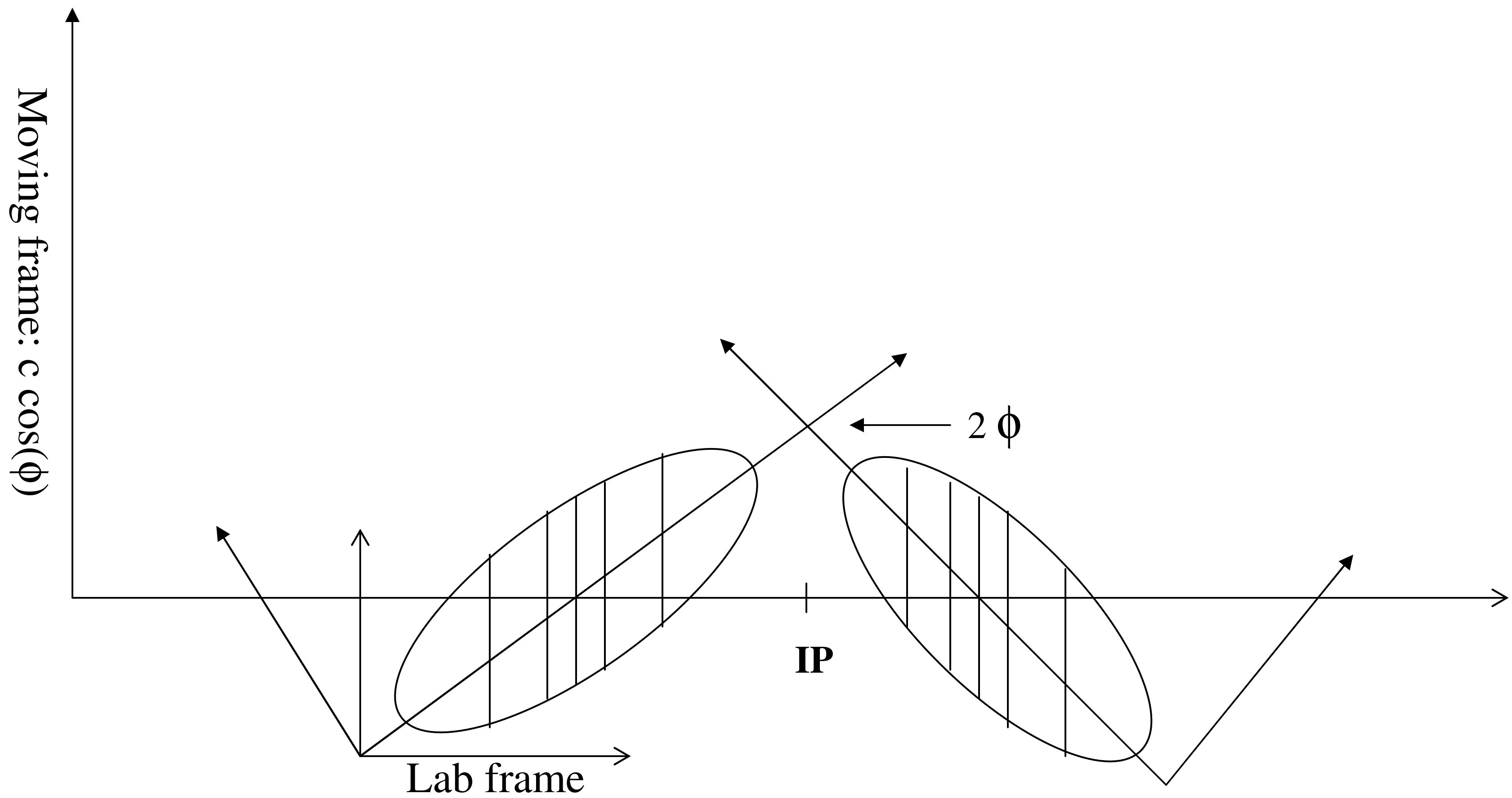
Ma: transfer map from head-on crossing angle
beam-beam collision

Mb,c: transfer maps from crab cavity deflection

M1-2: transfer maps between crab cavity and collision point

M: one turn transfer map of machine

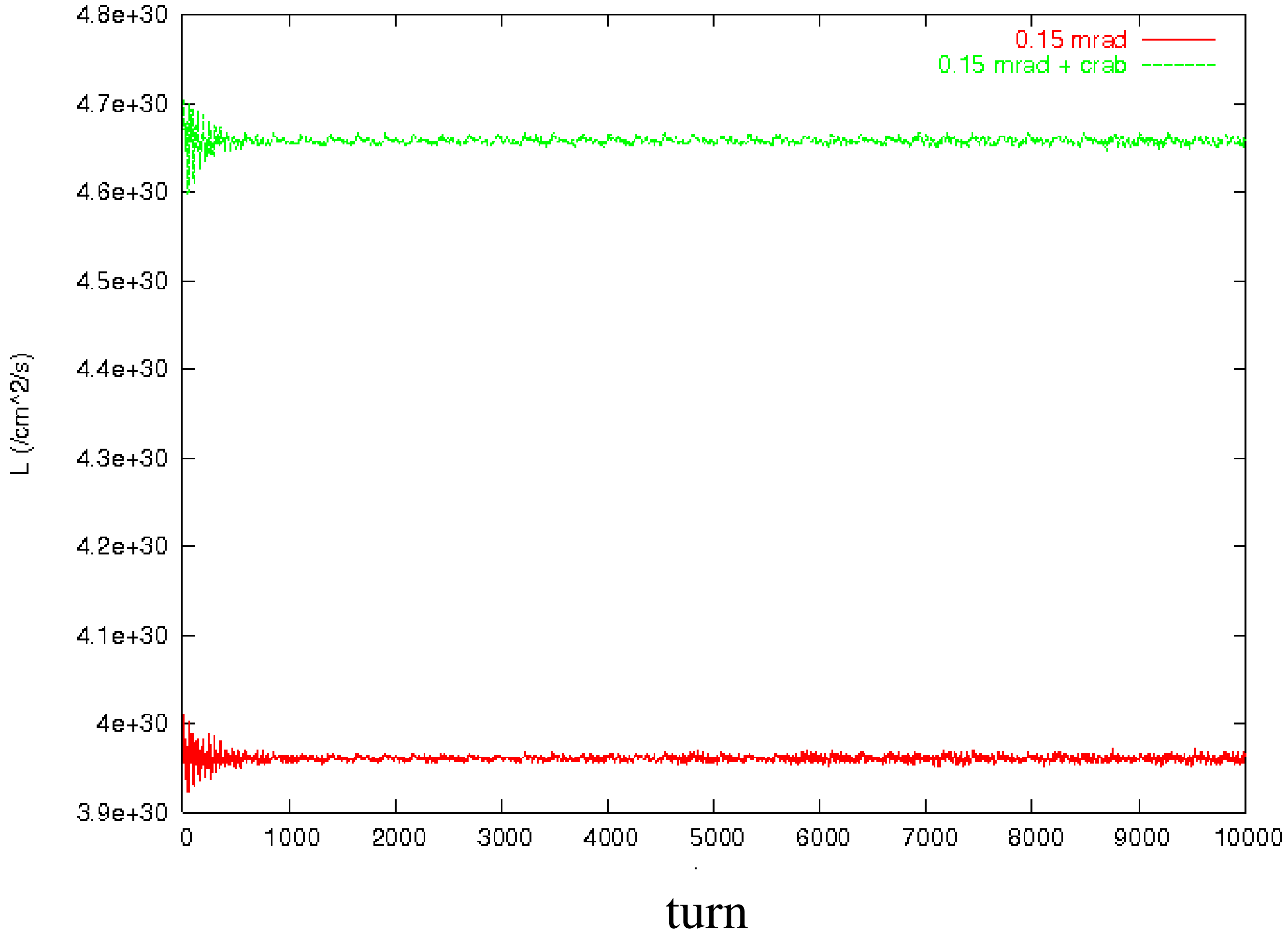
Head-on Beam-Beam Collision with Crossing Angle



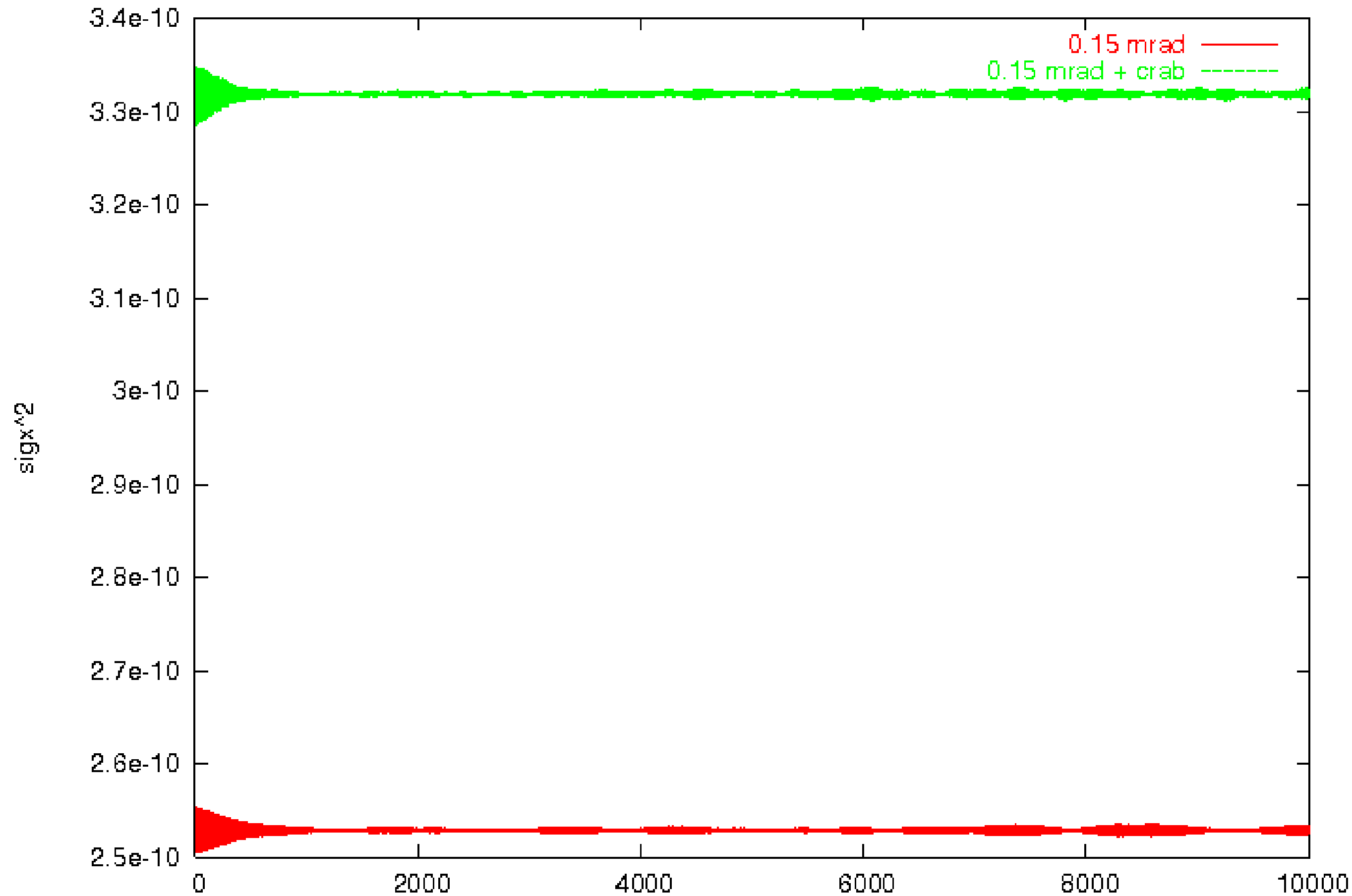
LHC Physical Parameters for Testing Crab Cavity

Beam energy (TeV)	7
Protons per bunch	10.5e10
β^*/β_{crab} (m)	0.5/4000
Rms spot size (mm)	0.01592
Betatron tunes	(0.31,0.32)
Rms bunch length (m)	0.077
Synchrotron tune	0.0019
Momentum spread	0.111e-3
Crab cavity RF frequency	400.8 MHz

Luminoisty Evolution with 0.15 mrad Half Crossing Angle with/without Crab Cavity

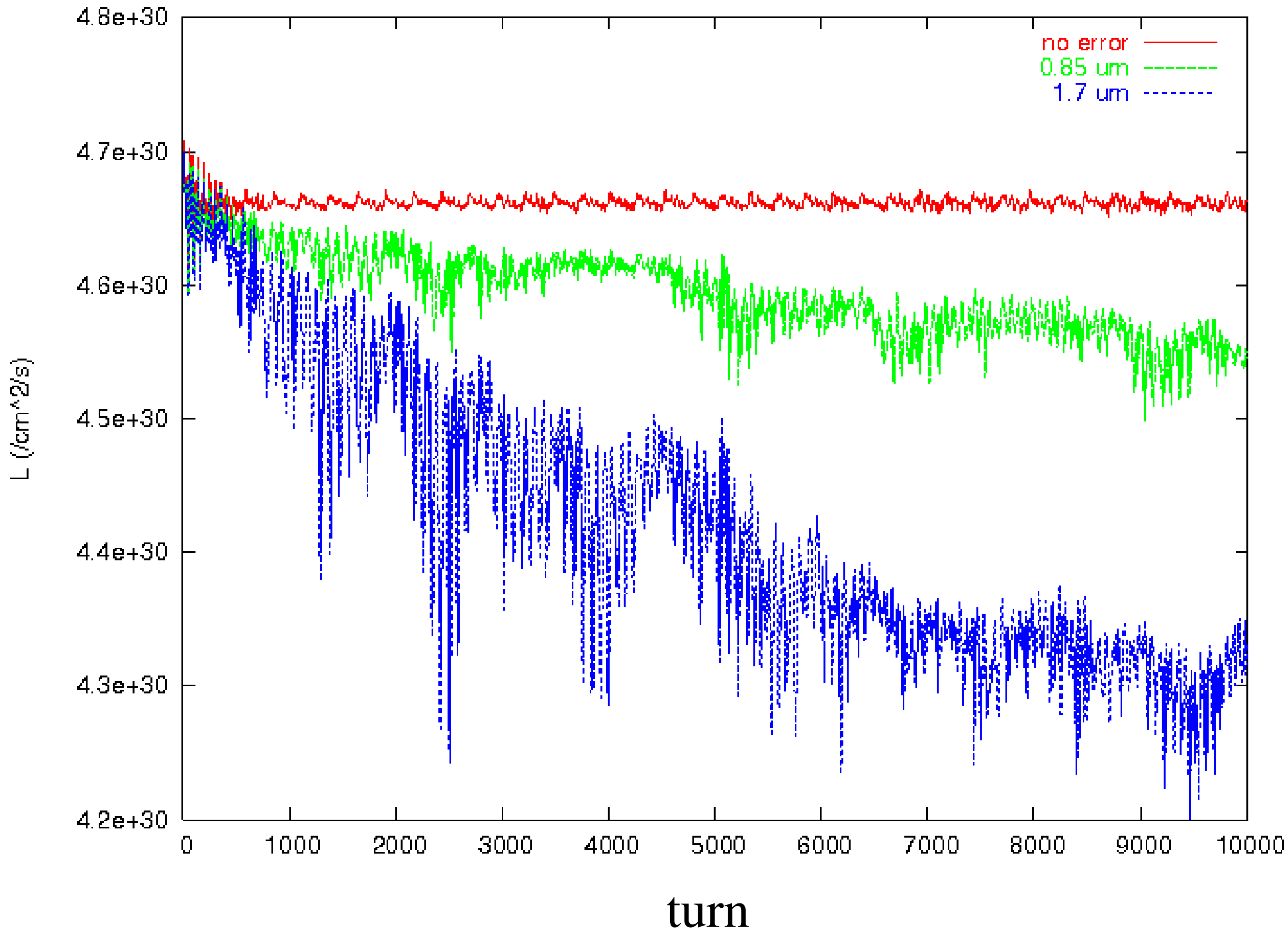


RMS Size Square with 0.15 mrad Half Crossing Angle with/without Crab Cavity

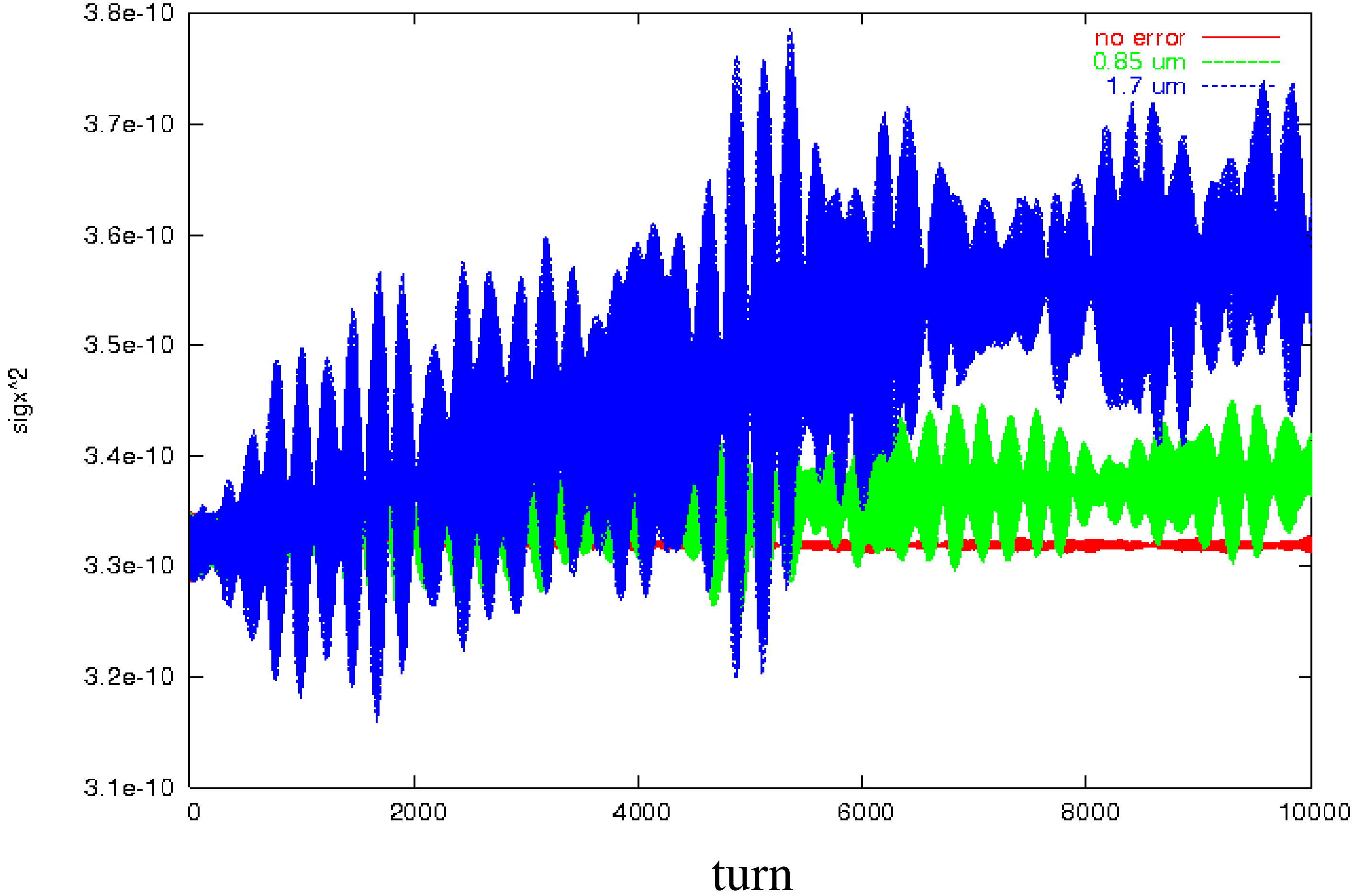


turn

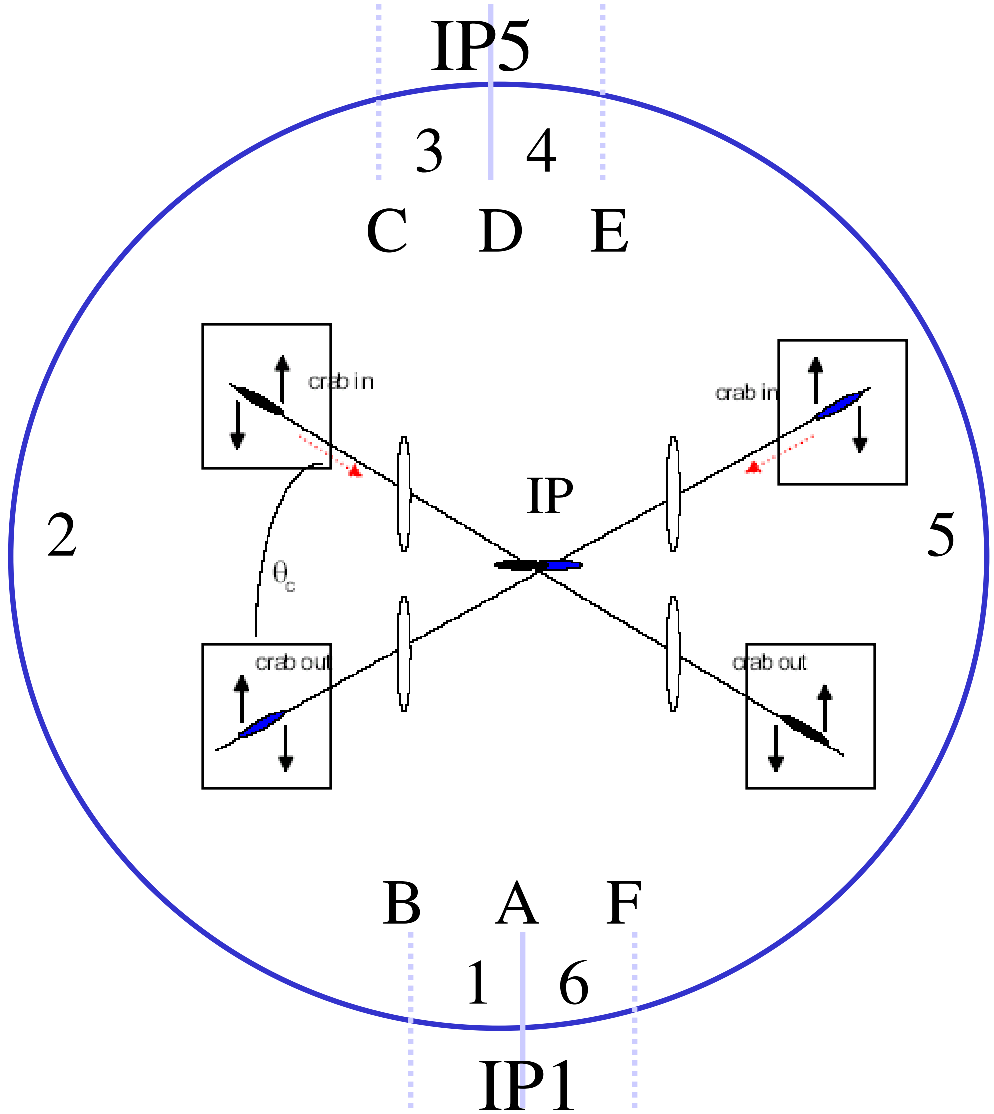
Luminoisty Evolution without/with 0.85 um and 1.7 um Horizontal Offset Noise



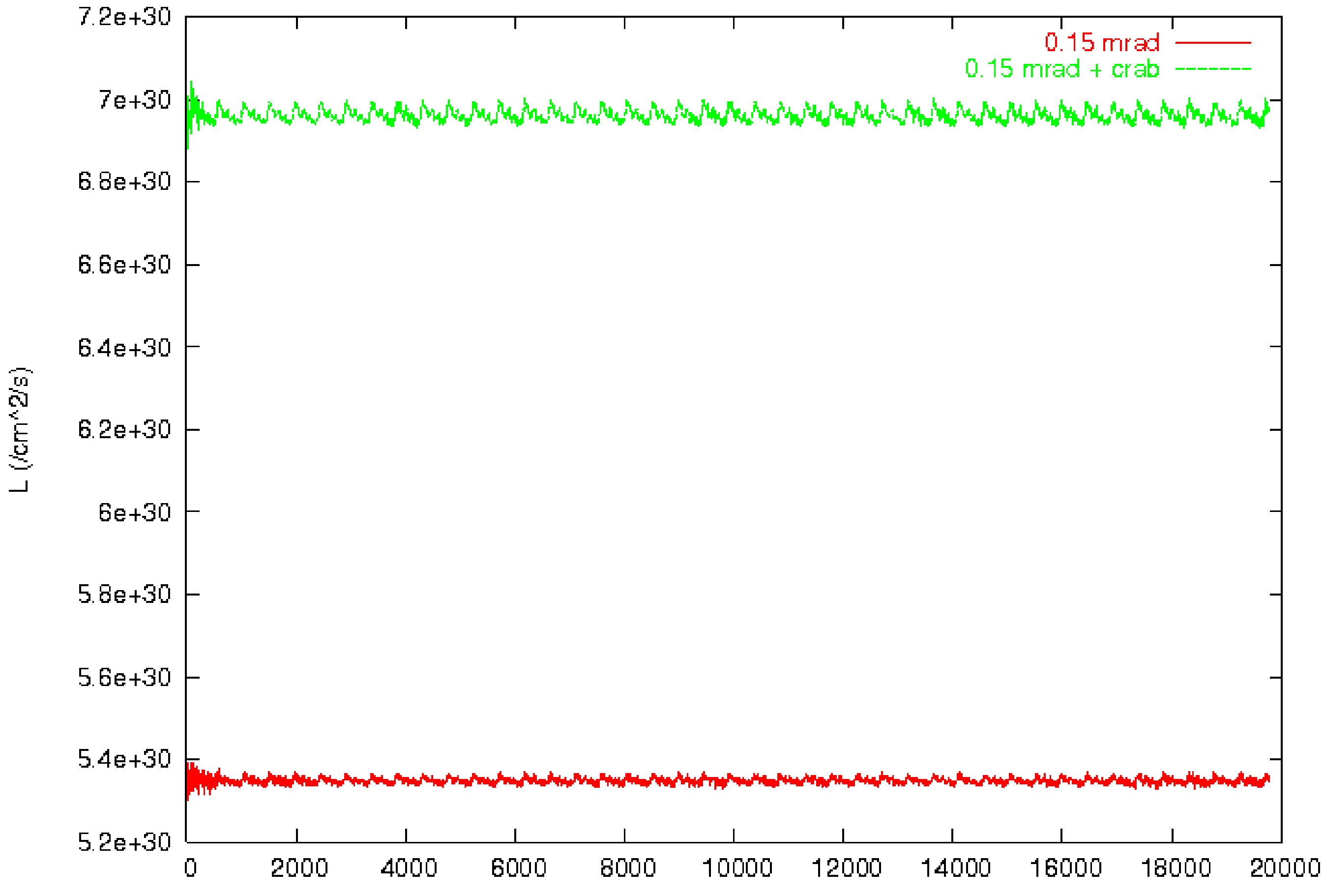
RMS Size Square Evolution without/with 0.85 um and 1.7 um Horizontal Offset Noise



A Schematic Plot of LHC Collision with 2 IPs and Crab Cavities



Luminoisty Evolution with 0.15 mrad Half Crossing Angle with/without Crab Cavity for LHC Upgrade



turn

Luminosity vs. Beta* for LHC Crab Cavity Compensation